

THE RESPONSE OF THE WHITE RAT TO TONAL STIMULI

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Our knowledge of the ability of animals to respond to tonal stimuli is at present in a rather unsatisfactory state. From the early work of Goltz on the dog to the present time investigators have been sharply divided on the point. Some have asserted that a given animal is utterly tone-deaf, while others assure us with equal conviction that the animal is perfectly capable of hearing tones. Indeed, contradictory results have even been obtained by the same worker with different experimental procedures. The problem thus not only piques one's scientific curiosity, but presents, as well, some aspects of considerable theoretical importance. A study of the literature on the subject led the writer to the belief that certain errors in experimental technique might be the basis for this confusion of results and the genesis of the present investigation lay in the hope that these errors could be avoided.

The early work on tone discrimination in the dog has been summarized in detail by Johnson (1913) and need not detain us here. It is sufficient to say that Johnson failed to find any evidence that dogs were capable of hearing tones and was thus unable to confirm the results of his predecessors. On the other hand, Anrep (1920), in view of Johnson's criticism of Pavlov and his co-workers, repeated the conditioned reflex experiments of the Russian school and was led to the conclusion that dogs were capable of a very fine degree of pitch discrimination.

¹ The writer wishes to express his appreciation to Professor John F. Shepard under whose guidance the present investigation was undertaken. To Professors Charles H. Griffitts and Carl R. Brown he is very greatly indebted for many helpful suggestions and much constructive criticism. He also extends his hearty thanks to Dr. Ella M. Hanawalt for her kind assistance.

Hunter attacked the problem with the white rat and, in a series of studies (1914, 1915, 1918), failed to train these animals to form a simple T-discrimination box habit with the tones of a tuning fork, whistle or violin. While there was an apparent response to the tones of these instruments, the habit invariably broke down when the noise element in the stimulus was removed. The work of Barber (1915) on sound localization seemed to confirm these results. However, in the present writer's opinion, a more detailed study of Hunter's latest investigation on the subject (1927) will reveal that the interpretation which Hunter puts upon his results is not the only one possible under the circumstances.

As in his earlier work Hunter here used a T-discrimination box in which the rats were trained to go to the right with the sound of a buzzer and to the left with silence. When this habit had been established, the tone of a tuning fork of 256 d.v., struck just before the animal was placed in the box, was added to the sound of the buzzer. Subsequently the buzzer was reduced in intensity about one-half "so that the tonal component dominated the stimulating situation." Finally the noise was completely eliminated and the tone alone given.

One rat failed to learn the original condition with the buzzer alone, while 4 rats apparently mastered the problem up to the time when the buzzer was entirely eliminated. With the fork tone alone Hunter considers that all rats failed to discriminate, in spite of the fact that one rat made a record of 9, 8, 6, 9, 8, 8, correct responses for the last six series of 10 trials each. Hunter implies that the rat is here responding to the noise of the hammer striking the fork, although he did not verify the point. Thus he says:

Had the electric fork been used, it is doubtful, in the light of all the facts published on the tonal sensitivity of the rat, that a discrimination would have been set up. Nevertheless, I now think that a test should have been made.

Hunter then tried using an intermittent tone as an auditory stimulus. The fork was struck 3.6 times per second from the time the rat was introduced into the box until he reached food.

He states that the above mentioned rat failed to master this problem after 210 trials and regards this as verifying his conclusions that this animal was not responding to the stimulus. A glance at the rat's record, however, reveals a different story. For the last 90 trials the animal made the following series of correct responses for successive groups of 10 trials: 7, 6, 6, 9, 8, 7, 7, 7, 7. To ignore such a record as this is, to say the least, decidedly unfair to the rat, for it is apparent that something other than pure chance is operating in this case. Were one to toss a coin one hundred times and get seven heads every ten tosses certainly the majority of observers would manifest a strong suspicion that something was decidedly peculiar about the coin or the way it was flipped. Yet Hunter would seemingly demand a record of 85 per cent for at least 50 trials before conceding any evidence of learning. It may be added that Johnson is even more rigid in his requirements. Thus he says:

The criterion of discrimination should not be less than a perfect record, maintained through at least three days. The arbitrary standard of 95 perfect trials in the last 100, which some investigators of other kinds of discriminations have adopted, may be allowable; but certainly a poorer record will not suffice.

It appears to the writer, however, that to demand such perfection of response from the animal as a criterion of discrimination is most unreasonable and arbitrary. After all, the problem is largely a matter of whether the animal can discriminate at all, and only secondarily whether he can always discriminate perfectly over a long period of time. It seems questionable that even the human, in difficult discriminations, can be called upon to establish such a high degree of accuracy. Lapses of attention are certainly inevitable as the result of the obtrusion of extraneous stimuli, emotional conditions and a host of other things. Surely if the animal can make a consistent record above 50 per cent in this type of discrimination experiment we are compelled to the conclusion that some characteristic of the situation is controlling the animal's behavior. Then if we eliminate all possible cues but the stimuli in question and the response is maintained to be abolished only when these

stimuli themselves are removed, what other conclusion is possible than that the animal is being affected by them? Why the rat does not respond in this case with the same accuracy that he does with other types of stimuli is certainly an interesting problem; nevertheless, it is not the one with which we are at present dealing.

In summing up his latest experiments Hunter concludes with the following statement:

There is as yet no evidence that the gross bodily behavior of the white rat can be controlled by tonal stimuli. The great mass of negative data makes it certain that the rat's sensitivity to tonal stimuli between the vibration frequencies of 256 and 4096 d.v. is very slight if it does exist.

The status of the problem remained about at this point until the recent work of Upton (1929) on tonal sensitivity in the guinea pig. He tried the usual T-discrimination box method with these animals, but failed to train them within 200 trials to go to the right with the tone of a Stern variator and to the left with silence. They also failed to discriminate in the same number of trials between a tone of 300 and one of 800 d.v. The animals were likewise unable to learn to go toward a source of tone. These results led Upton to conclude that:

. . . . the discrimination-maze method is useless for problems involving tonal discrimination because it does not offer adequate possibility of control. It is impossible to eliminate from the situation other auditory stimuli, and the stimuli furnished by the animal's own body due to hunger and other unpredictable conditions which may exist in the organism.

We can not help but feel that Upton is here exaggerating the difficulties to be encountered with the discrimination box method. Why should extraneous stimuli be so much more difficult to eliminate here than in any other type of discrimination experiment? Obviously visual stimuli can be removed by running the animals in the dark and extraneous auditory stimuli reduced greatly by conducting the tests in a sound-proof room and carpeting the floor of the discrimination box. The other "unpredictable conditions

which may exist in the organism" are quite as prevalent in other methods of experimentation. Certainly they are by no means eliminated in the technique which Upton finally adopted.

His method was to *confine* the animal in a suitable holder which was connected with a tambour type pneumograph. This apparatus was placed in a sound-proof box containing a loud speaker. Aluminum electrodes were attached to the hind legs of the animal for the purpose of administering an electric shock. Presentation of the tone alone was not correlated with any change in the respiratory rhythm which was normally very irregular under the conditions of the experiment. The conditioning procedure was to present the tone for a short time and, while the tone was still going on, to administer the shock. After several hundred trials the tone alone produced a pronounced increase in the amplitude of the breathing cycle.

In later experiments (1929) Upton used this method for the purpose of testing the effects of long exposure to a tone on the conditioned response to that tone. He found that exposure to a tone of 600 d.v. for a period of seventy days was followed by a reduction in the sensitivity of the animals to that tone, although the response to one of 1000 d.v. was unimpaired.

Other recent investigations on other mammals have yielded evidence of the ability of these forms to respond to tones. Thus Forbes, Miller and O'Connor (1927) recorded action currents from the auditory nerve of the decerebrate cat when the animal was stimulated by a tuning fork; and Corbeille and Baldes (1929) have reported changes in the respiratory and cardiac rhythm in frogs, rabbits, dogs and cats when these animals were presented with tones of an audio oscillator. Such investigations as these certainly indicate that the ears of near relatives of the white rat are at least capable of picking up tonal vibrations and it seems hardly reasonable to suppose that there is anything strangely different about the rat's ear which would render it irresponsive to this type of stimulation in the way Hunter seems to imply.

In general, a careful consideration of the studies described above will reveal quite plainly, we believe, that our problem is more complex than it would appear to be at first glance and that in

reality we are dealing with something more than a simple sense organ process. The conditioned reflex experiments of Anrep and Upton indicate that the ear of the dog and the guinea pig is responsive to tonal vibrations. That the discrimination box experiments of Johnson and Upton do not disprove this contention they both tacitly admit, but that these investigations do raise interesting problems as to the learning processes involved is quite evident. So far as the dog and the guinea pig are concerned they reveal the presence of at least three problems which require further investigation: (1) Is it impossible to get these animals to respond to tonal stimuli by means of the discrimination box method? (2) Why should it be so much more difficult to form this habit with tonal stimuli than with, for example, light? (3) Why should it be more difficult to establish the discrimination box habit to tonal stimuli than to condition a reflex to such stimuli? As regards the white rat we have the additional problem of discovering whether or not this animal is actually capable of responding to tones.

That Hunter has not settled this last problem may be reasonably inferred from the results with the dog and the guinea pig. Moreover, there are no gross differences from the human in the anatomy of the inner ear of the rat which would lead us to expect such a difference in the sensory mechanism of tone and noise as Hunter postulates (Wada (1923)). But further than this, in the writer's opinion, the discrimination box experiments have not shown beyond a reasonable doubt that any of these animals is incapable of conditioning the locomotor responses to tones. In all of Hunter's experiments the tone was accompanied by a noise of some sort, whether it be the clang of the hammer on the tuning fork or the rush of air with the whistle and organ pipe. It may be possible that the rat's nervous system is so organized that noise is a more effective stimulus than a tone and, as a consequence, the habit is built up around the noise element. Subsequent elimination of the noise from the stimulus tone would, therefore, disturb the habit; but the conclusion that the animal is consequently incapable of learning to respond to the tone is certainly

not indicated, particularly since there is a modicum of evidence in Hunter's own experiments in favor of a response to tone. Plainly if we are going to ascertain definitely whether or not the rat is capable of conditioning his locomotor system to tonal stimuli we must put him in a situation where the tonal element stands out clearly and where any accompanying noises or extraneous stimuli are eliminated or reduced to a minimum. With these considerations in view the present investigation was undertaken in the hope of settling definitely the problem of the sensitivity of the white rat to tonal stimuli and of the capacity of this animal to form the discrimination box habit on the basis of such stimuli.

APPARATUS

Recent developments in radio telephony and the thermionic vacuum tube have provided relatively simple and inexpensive generators of alternating current power of frequencies ranging from a fraction of a cycle per second to millions of cycles. Such a generator coupled with a loudspeaker of the high quality now available provides a simplicity and flexibility of control which, although by no means ideal, far surpasses any other sound source for the purposes in which we are at present interested. For this reason such a system was thought best for this investigation. The oscillator circuit was of the Hartley type, the theory of which has been described in many places, notably by van der Bijl (1920) and Morecroft (1927) and needs no discussion here.

The output circuit was inductively coupled to the generator and controlled by a potentiometer. The current from the potentiometer was fed into a loudspeaker unit of the balanced armature type. This type of receiver is generally conceded to be superior to the ordinary telephone receiver since the diaphragm is not subjected to a constant pull from the permanent magnets as is the latter type of instrument. The balanced form is of course not ideal and unquestionably generates certain inharmonic partials when the excitation is heavy. Nevertheless, the end result is sufficiently good for our present purpose. The tone is

fairly pure and devoid of noise so far as the human ear is concerned.²

The discrimination box was located in a small sound-proof room adjoining the room in which the oscillator, control panel and rat cages were placed. In the preliminary experiments the box illustrated in figure 1 was used. The walls were constructed of $\frac{3}{4}$ -inch lumber and the top of $\frac{1}{2}$ -inch wire mesh. The walls and floor were lined with black felt to reduce the noises made by the rats in running. The doors leading to the food-boxes Bl and Br were of wire mesh to eliminate differences in air currents or

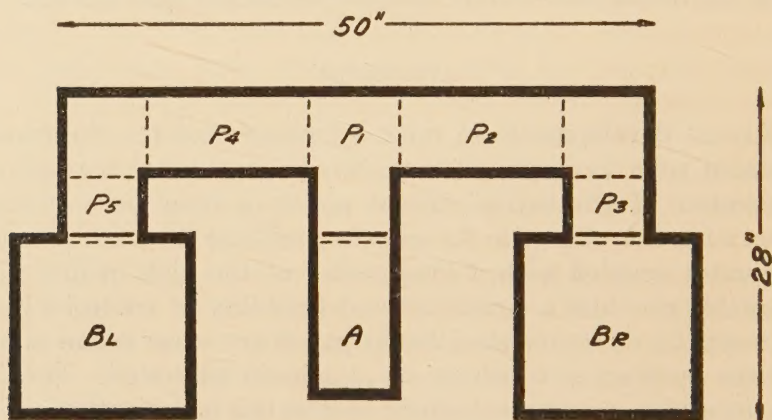


FIG. 1. DISCRIMINATION BOX USED IN EXPERIMENT I

reverberations which might possibly develop with one or the other of the doors in the closed position. The door leading from the entrance chamber A was of aluminum and operated pneumatically.

The floor of the alleys was set up in separate sections p1, p2, p3, p4, and p5, each of which was hinged at one end and held in place by a spring. Contacts were placed under each in such a fashion that the weight of the rat served to depress a given section just

² Oscillograph records of the current revealed a perfectly regular wave with a faint trace of a second harmonic. While this is by no means an absolute indication of the purity of the tone, in view of the quality of the loudspeaker, it is to be presumed that the tone was relatively pure and free of noise.

sufficiently to make contact. These contact points were connected with lights on a switchboard located in the adjoining room. The system was wired so that in case the animal made a correct response white lights would show his progress through the box, while in case of error red lights would flash on. Over sections p1, p2, and p4 shocking grids of copper screening were laid. These were actuated from the 110 volt circuit through step-down transformers and controlled by a rheostat.

Immediately around the discrimination box was built an enclosing chamber lined with celotex and 1-inch hair felt. While not completely sound-proof this chamber served to eliminate the respiratory sounds and slight movements made by the experimenter and also served to screen him from the animal. In the earlier experiments the animal was observed through a small peephole.

The initial click of the loudspeaker was eliminated by enclosing this unit in a sound-proof box located directly in front of the entrance alley A. The lid of this box was raised pneumatically by the same mechanism that operated the entrance door and the system was so arranged that the sound-proof box opened about one second before the entrance door whether or not the tone was being sounded.

EXPERIMENT I

Procedure. In the first experiment an attempt was made to train 4 rats, 2 males and 2 females each about six months old, to go to the right with a tone of fundamental pitch 1024 d.v. and to the left with silence. Each animal was given 10 trials per day in rotation. Thus rat A was given a trial, then rat B and so on until each of the four had been given one trial. Rat A then received his second trial, followed by rat B, etc. In this way each animal was given an interval of a few minutes between trials with the view to reducing the tendency to set up position or alternation habits. The order of presentation of the sound was determined by tossing coins, the result being slightly modified such that in each series of 10 trials the animal was required to go five times to the right and five times to the left. The evaluation of error

was simplified by the fact that the animals almost invariably proceeded up to the closed door of the food-box and only a fraction of 1 per cent of the time reversed their course in the middle of an alley. Since these occurrences were so exceptionally rare they are included in the tables as complete errors in the case of starting correctly and turning back, while the reverse were considered as correct responses.

For each trial the procedure was as follows: After properly setting the food-box doors the rat was introduced at *A* (fig. 1) and the door of the enclosing chamber shut. The switch operating the lid of the sound-proof box and the entrance door was then closed and held thus until the rat reached the food whether or not the tone was being sounded. During the first few trials the animals were shocked in case of error, but this method of punishment proved so difficult to control and had such a disturbing effect on the rats that it was soon abandoned. Thereafter the desire for food was presumably the sole drive. In each of the food-boxes was placed a pan of McCollum mixture from which the rat was permitted to nibble for a few seconds. He was then returned to the cage and the next animal started. After the day's run the rats were given additional food in the cages to an amount sufficient to keep them at a proper weight.

Results. After 490 trials the combined average of all the rats was only 51.4 per cent and since none of them gave any evidence of learning the experiment was discontinued.

EXPERIMENT II

From observations of the behavior of the animals in the first experiment it was concluded that their failure to respond to the tone might, in part at least, be accounted for by reference to certain aspects of the procedure. (1) After the abandonment of the shock as a punishment the only consequences of error to the rat were the increased length of time and energy required to reach the food. But since the rats soon came to run through the box with great rapidity, errors were rectified very quickly and it is conceivable that the additional time and energy needed may have become a negligible factor for learning. (2) The lid of the sound-

proof box was opened relatively slowly and because of its gradual development in intensity the tone may have lost something of its stimulating value through adaptation effects. (3) It has been the experience of the writer that young rats are apparently much more reactive to noise than are the older rats and it was thought that this might possibly be true of tones as well. Hence, positive results might be obtained with rats considerably younger than those used in the first experiment. With these points in mind it

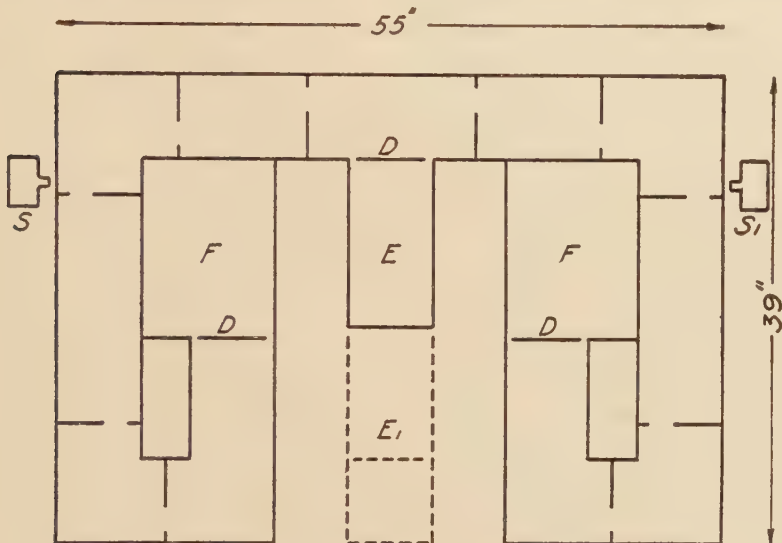


FIG. 2. DISCRIMINATION BOX USED IN EXPERIMENTS II AND III

was deemed advisable to make the changes described below in the apparatus and procedure.

The first discrimination box was discarded and the one depicted in figure 2 substituted in its place. As will be observed the length of the path is considerably increased over that of the first box. The walls and the top were constructed of wire mesh and partitions were placed in the alleys as indicated. Holes were cut in these just large enough to allow the rat to squeeze through and it was hoped that these together with the added length of alley might render the consequences of error more formidable.

The floor was covered with $\frac{1}{4}$ -inch carpeting and in electrical connection with the control panel as before. At first the entrance alley *E* was used, but later this was lengthened to the extent indicated by the broken lines. The sound-proof box was abandoned and two identical loudspeaker units were mounted at the sides of the discrimination box at the points *S* and *S*₁. These were suspended from the roof of the enclosing chamber and not in contact with the discrimination box. It was decided to ignore for the time being the initial click given by these receivers and to take advantage of the suddenness of onset of the tone.

Procedure. In this experiment 5 thirty-day-old litter mates were used, 4 females and 1 male. The animals were run in rotation as before. Ten trials per day were given for the first twenty-seven days after which the rats received 20 trials per day for the remainder of the experiment. In view of Wylie's (1919) finding that rats could be trained to go away from a noise more readily than toward it, the attempt was made in the present experiment to train the rats to go to the right with a tone on the left and to the left with a tone on the right. In this case a tone of 3072 d.v. was used. As before, the switch operating the entrance door also started the tone which was maintained until the rat reached the food. With these exceptions the procedure at the start was the same as in the first experiment.

Results. An inspection of the learning curve of figure 3 and of the data provided in table 1 reveals the interesting fact that for the first 100 trials the rats ran consistently below 50 per cent, the general average being 45.4 per cent. This would seem to indicate in these rats a tendency to go toward the tone rather than away from it, a point which might in part explain the long time required to learn the opposite habit. Perhaps, however, we are not justified in accepting this interpretation without further experimentation.

At the end of 200 trials the general average had risen to 51.6 per cent. At this point the tone from the right hand unit was abandoned and the animals were now required to go to the right with a tone on the left and to the left with silence (*A*, fig. 3). In the next 50 trials the curves of nos. 1, 2 and 5 dropped, with

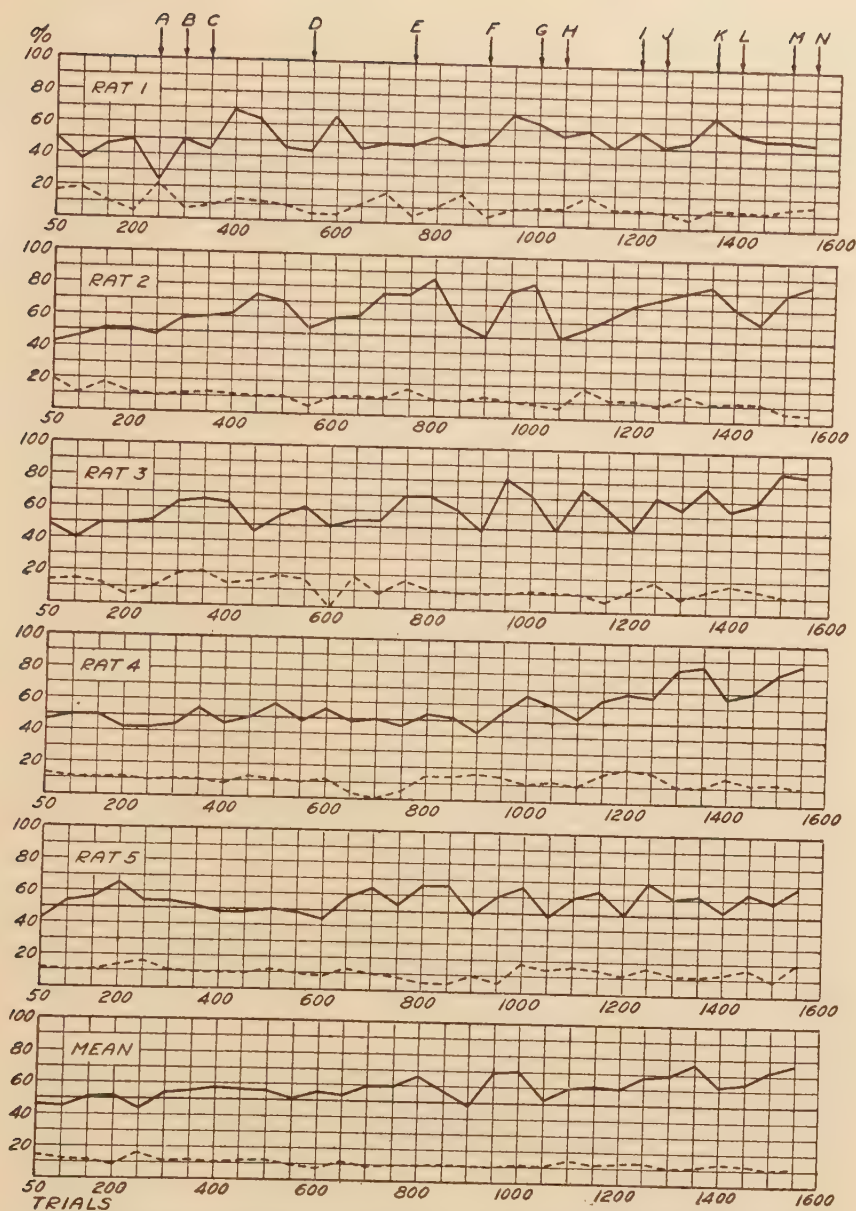


FIG. 3. LEARNING CURVES FOR 5 ANIMALS PLOTTED AT 50-TRIAL INTERVALS

The data are given in table 1. The letters at the top have the following significance: A, right-hand and tone abandoned; B, amplifier added; C, entrance alley lengthened; D to E, animals run by different experimenter; F, no-tone control period; G, sound started before the animal is taken into the sound-proof room; H, no-tone control period; I, entrance alley lengthened further; J, animals run in the dark from this point to the end of experiment; K, possible cues from the experimenter controlled; L, amplifier removed; M, vibrissae clipped.

TABLE I

SERIES OF 10 TRIALS	DATE	REMARKS	CORRECT RESPONSES PER 10 TRIALS.					MEAN FOR 10 TRIALS	MEAN FOR 50 TRIALS	ERRORS WITH SOUND	ERRORS WITHOUT SOUND
			RAT 1	RAT 2	RAT 3	RAT 4	RAT 5				
1	7/9		8	2	5	4	3	4.4		13	15
2	10		4	4	5	7	3	4.6		9	18
3	11		3	7	7	5	6	5.6		9	13
4	12		5	6	4	3	5	4.6		14	13
5	13		5	2	3	4	4	3.6		19	13
		MEAN	5.0	4.2	4.8	4.6	4.2		4.56	12.8	14.4
		σ	1.67	1.88	1.32	1.35	1.16	1.47			
6	14		2	6	5	6	4	4.6		11	16
7	15		5	5	3	6	6	5.0		14	11
8	16		1	4	2	5	5	3.4		17	16
9	17		4	5	6	5	5	5.0		16	9
10	18		6	3	4	3	7	4.6		13	10
		MEAN	3.6	4.6	4.0	5.0	5.4		4.52	14.2	12.4
		σ	1.85	1.02	1.41	1.09	1.02	1.27			
11	19		3	4	5	6	4	4.4		14	14
12	20		6	8	6	5	7	6.4		11	7
13	22		4	3	4	3	6	4.0		18	12
14	23		5	5	6	6	4	5.2		11	13
15	24		5	6	4	5	7	5.4		13	10
		MEAN	4.6	5.2	5.0	5.0	5.6		5.08	13.4	11.2
		σ	1.02	1.72	1.26	1.09	1.02	1.22			
16	25		5	6	5	6	8	6.0		10	10
17	26		5	4	5	3	7	4.8		13	13
18	27		5	7	5	4	7	5.6		13	9
19	28		4	5	4	3	4	4.0		18	12
20	29		5	4	6	5	7	5.4		14	9
		MEAN	4.8	5.2	5.0	4.2	6.6		5.16	13.6	10.6
		σ	.4	1.16	.63	1.16	1.35	.87			
21	30		5	4	6	5	3	4.6		14	13
22	31		5	6	6	5	6	5.6		13	9
23	8/1		2	5	5	4	5	4.2		19	10
24	2		0	4	4	3	8	3.8		21	10
25	3		0	5	5	4	5	3.8		24	7
		MEAN	2.4	4.8	5.2	4.2	5.4		4.40	18.2	9.8
		σ	2.24	.98	.98	.98	1.62	1.63			
26	4		5	5	8	6	7	6.2		13	6
27	5		6	7	5	5	4	5.4		14	9
28			5	7	9	3	5	5.8		12	9
29	6		4	6	4	4	5	4.6		11	16
30			5	4	6	4	6	5.0		9	16
		MEAN	5.0	5.8	6.4	4.4	5.4		5.40	11.8	11.2
		σ	.63	1.16	1.85	1.02	1.02	1.13			
31	7		5	7	9	5	6	6.4		8	10
32			3	5	5	6	4	4.6		14	13
33	8		5	7	9	6	6	6.6		2	15
34			4	6	6	4	5	5.0		9	16
35	9		5	5	4	7	5	5.2		4	20
		MEAN	4.4	6.0	6.6	5.6	5.2		5.56	7.4	14.8
		σ	.80	1.26	2.06	1.02	.98	1.22			
36	10		5	5	7	4	5	5.2		5	19
37			6	5	8	4	3	5.2		8	16
38	11		7	8	6	4	5	6.0		5	15
39			7	7	4	5	6	5.8		13	8
40	12		9	6	7	6	5	6.6		10	7
		MEAN	6.8	6.2	6.4	4.6	4.8		5.76	8.2	13.0
		σ	1.32	1.16	1.35	.80	.97	1.12			

TABLE 1-CONTINUED

SERIES OF 10 TRIALS	DATE	REMARKS	CORRECT RESPONSES PER 10 TRIALS					MEAN FOR 10 TRIALS	MEAN FOR 50 TRIALS	ERRORS WITH SOUND	ERRORS WITHOUT SOUND
			RAT 1	RAT 2	RAT 3	RAT 4	RAT 5				
41	8/13		4	7	6	7	6	6.0		9	11
42			7	7	6	4	5	5.8		7	14
43			7	6	5	4	5	5.4		9	14
44			7	8	2	6	3	5.2		10	14
45			7	9	4	4	5	5.8		10	11
		MEAN	6.4	7.4	4.6	5.0	4.8		5.64	9.0	12.8
		σ	1.20	1.02	1.49	1.26	.97	1.18			
46	15		6	5	6	5	3	5.0		12	13
47	16		5	8	7	4	5	5.8		7	14
48			3	7	2	7	5	4.8		14	12
49			4	7	6	7	7	6.2		8	11
50	17		5	8	7	6	5	6.2		3	16
		MEAN	4.6	7.0	5.6	5.8	5.0		5.60	8.8	13.2
		σ	1.02	1.09	1.85	1.16	1.26	1.27			
51	18	RUN BY E.H.	5	6	7	5	5	5.6		8	14
52			4	6	9	4	5	5.6		6	16
53			4	5	5	4	4	4.4		3	25
54			4	5	4	6	6	5.0		4	21
55	19		5	5	6	5	4	5.0		4	21
		MEAN	4.4	5.4	6.2	4.8	4.8		5.12	5.0	19.4
		σ	.49	.49	1.72	.98	.98	.93			
56	20		6	5	5	5	3	4.8		4	22
57	21	RUN BY E.H.	7	6	5	5	4	5.4		4	19
58			7	6	5	5	5	5.6		3	19
59			6	5	5	5	5	5.2		1	23
60	22		7	8	5	8	5	6.6		1	16
		MEAN	6.6	6.0	5.0	5.6	4.4		5.52	2.6	19.8
		σ	.49	1.09	0	1.20	.80	.71			
61	23	RUN BY E.H.	3	4	5	5	4	4.2		6	23
62			4	7	4	5	6	5.2		4	20
63			4	7	8	5	8	6.4		7	11
64			6	6	7	5	5	5.8		4	17
65	24		6	7	3	4	6	5.2		9	15
		MEAN	4.6	6.2	5.4	4.8	5.8		5.36	6.0	17.2
		σ	1.11	1.16	1.85	.40	1.32	1.17			
66	25		2	8	4	5	7	5.2		4	20
67	26	RUN BY E.H.	6	7	6	5	6	6.0		6	14
68			4	8	6	5	8	6.2		7	22
69			7	9	5	5	5	6.2		4	15
70	27		6	6	6	5	6	5.8		5	16
		MEAN	5.0	7.6	5.4	5.0	6.4		5.88	5.2	17.4
		σ	1.79	1.02	.80	0	1.02	.92			
71	28	RUN BY E.H.	4	8	5	5	4	5.2		7	17
72			5	10	8	4	6	6.6		3	14
73			5	5	5	5	6	5.2		8	16
74			5	8	7	5	5	6.0		6	14
75	29		5	7	10	4	6	6.4		3	15
		MEAN	4.8	7.6	7.0	4.6	5.4		5.88	5.4	15.2
		σ	.40	1.62	1.67	.49	.80	.99			
76	30		4	7	9	4	7	6.2		1	18
77	9/2		7	10	6	5	7	7.0		2	13
78			5	9	7	4	7	6.4		7	11
79			5	9	7	6	6	6.6		6	11
80	3		6	8	6	8	6	6.8		7	9
		MEAN	5.4	8.6	7.0	5.4	6.6		6.60	4.6	12.4
		σ	1.02	1.02	1.09	1.49	.49	1.02			

the result that the general average fell to 44 per cent. Here again we may have some evidence that the sound stimulus or something correlated with it was affecting the animals' behavior, although it is questionable whether the change is statistically significant.

At the end of 250 trials the tone was approximately doubled in intensity (*B*, fig. 3) by means of a resistance coupled amplifier. For the subsequent 50 trials the general average increased to 54 per cent. Since at this time the door of the entrance alley was located at the junction of the *T*, the rat could make his choice directly the door was opened. In order that the animal might be subjected to the tone a little longer before making a choice the entrance alley was lengthened (*C*, fig. 3) and the animal was introduced at *E*₁ (fig. 2). For the following 550 trials no further changes in the procedure were made except for a period of 250 trials during which the animals were run by another experimenter (*D* to *E*, fig. 3). This change was followed by a slight disturbance and the general average fell from 56 to 51.2 per cent in the following 50 trials. When the original experimenter took over the animals again they had reached an average of 58.8 per cent and the further change produced no disturbance.

After 850 trials nos. 2 and 3 gave distinct evidence of learning and no. 5 a slight amount, while nos. 1 and 4 had shown little or no progress. At this point a control was instituted by running the animals for 50 trials without the tone (*F*, fig. 3). Otherwise the procedure was unchanged. Half of the time the left food-box was closed and half of the time the right in the usual random order; but no stimulus tone was presented at any time. During this 50-trial period all of the animals fell to 50 per cent or below with a resulting general average of 48 per cent. Although this indicates that the animals were getting their cue from the sound stimulus, this type of control is subject to Johnson's criticism that the rats might have been reacting to some cue unwittingly provided by the experimenter, which he, expecting them to fail, no longer gave. The tone was then presented during the following 50 trials as before and all the rats improved markedly with an average of 68.8 per cent for that period.

In order to eliminate the initial click of the loudspeaker as a

possible cue the tone was now started before the animals were taken into the sound-proof room (*G*, fig. 3). This appeared to have no effect as the rats finished 50 trials of this procedure with an average of 70.4 per cent. Following this another 50 trials with no tone was given (*H*, fig. 3). This time nos. 2, 3 and 5 dropped to 50 per cent, while nos. 1 and 4 made records of 56 and 60 per cent respectively. This rather unexpected result on the part of these animals seemed to indicate that they were previously reacting to something other than the sound. Since the discrimination box was of wire mesh it was remotely possible that the rats could see the open food-box doors and were reacting accordingly. To control this the entrance alleys were lined with black cloth and the animals run for 50 trials with the sound as usual. All the rats continued to improve except no. 4 whose average fell to 52 per cent. Apparently she was getting some visual cue. Another 50 trials, however, and she was back to 64 per cent.

Throughout most of the experiment the animals had given evidence of being emotionally disturbed by their short confinement in the entrance box. They would bite and pull at the door and sides of the box in their eagerness to get to the food. An attempt was now made to eliminate this factor by extending the entrance alley and removing the entrance door. Accordingly an alley 4 feet in length was constructed and placed outside the chamber enclosing the discrimination box. A tube 2 inches in diameter and 5 inches long connected the new alley with E_1 (fig. 2) through the wall of the enclosing chamber. The entrance door in E_1 was removed so that the animal was free to proceed as soon as he was introduced into the end of the new entrance alley. This change (*I*, fig. 3) proved disturbing at first, but recovery was rapid. From this point (*J*, fig. 3) throughout the remainder of the experiment the animals were run in the dark and their progress through the box observed from the lights on the control panel in the adjoining room. The change from light to darkness, while slowing the rats down for a few trials, had no apparent effect on their record.

At the end of 1300 trials another control was instituted (*K*, fig. 3). To check the possibility that the behavior of the animals was being determined by some cue from the experimenter the

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order of presentation was controlled by an assistant. Since the experimenter could hear when the tone was going a small portable oscillator was strapped to his back and connected with a set of head phones. The stimulus tone was thus effectually drowned out and the experimenter kept in ignorance of the direction to be taken by the rat. Far from disturbing the animals this procedure seemed actually beneficial as they exhibited a marked improvement during the subsequent 50 trials. Plainly they were getting no help from the experimenter. The amplifier was then removed reducing the intensity of the stimulus tone about one-half (*L*, fig. 3). As might be expected this proved to be a disturbance at first, but the animals soon became accustomed to the change.

The controls thus far attempted had shown that the animals were not responding to the initial click of the loudspeaker, to visual cues, or to stimuli provided by the operator. There remained, beside the tone itself, three other possibilities to consider: (1) that the animals' vibrissae were resonating to the tone and providing the animals with a tactual stimulus; (2) that the box itself was resonating and affecting the animals through vibrations of the floor; (3) that the animals had established an alternation habit or rhythm of responses which accidentally coincided with the order of presentation of the stimuli. To control the first of these the vibrissae were clipped off (*M*, fig. 3). The animals were slowed up somewhat, but their records revealed no change. To check the second possibility a microphone was constructed from two 10-inch arc-light carbons. When this was connected in series with a battery and head-phones it was sufficiently sensitive to pick up the constant vibrations of the building. With the microphone mounted on the discrimination box it was just possible to pick out the tone with the amplifier on. After the carbons were swathed in felt the tonal element was markedly reduced indicating that the carbons were probably resonating to the tone directly. When the rat was running through the box the microphone was agitated so violently that the tone was rendered inaudible in the phones. Since the movements of the rats produced such a vibration of the box, the likelihood that the animals were responding to any oscillations of the floor generated by the

tone seemed remote. However, this point was conclusively disposed of by the third experiment which will be described later.

That the animals had developed no alternation habit or rhythm of responses may be observed from the order which they actually took when making a good record. Thus a five day interval during which no. 2 made a record of 84 per cent her responses were as follows:

L L R L R L R R L R	100 per cent
R L R R R R L R L R	80 per cent
R R R R L R L L R L	90 per cent
L L R R L R R R R L	70 per cent
R R L R R L R L L L	80 per cent

During the same period no. 3 made the following record:

L L L R L R L R R L	70 per cent
R R R R R R R L R R	60 per cent
R L R L R L L R L R	80 per cent
R L L L R L R R L R	80 per cent
L R L R R L L R L R	100 per cent

An inspection of these records reveals a tendency to go to the right rather than to the left, but certainly it is difficult to find any evidence of an alternation habit of even a complex character.

When the rats had been given a total of 1550 trials the experiment was stopped. During the last 50-trial period the general average was 76.4 per cent. A glance at the curves of the individual animals (fig. 3), however, will show that this average does some of the rats an injustice. Rats 1 and 5 never gave conclusive evidence of learning. While their curves run consistently above the 50 per cent line they were never far enough above for any length of time to make the evidence clean cut, and they both held down the average of the group. On the other hand, nos. 2, 3 and 4 did not fall below 80 per cent in the last 100 trials. Rat 2 caught on most quickly and after 300 trials never dropped to the 50 per cent line except during the no-tone control periods. Rat 3 required 600 trials before she became consistent and no. 4 needed 800.

The progress of the animals is shown in an interesting form by the frequency curves of figure 4. Here the number of correct

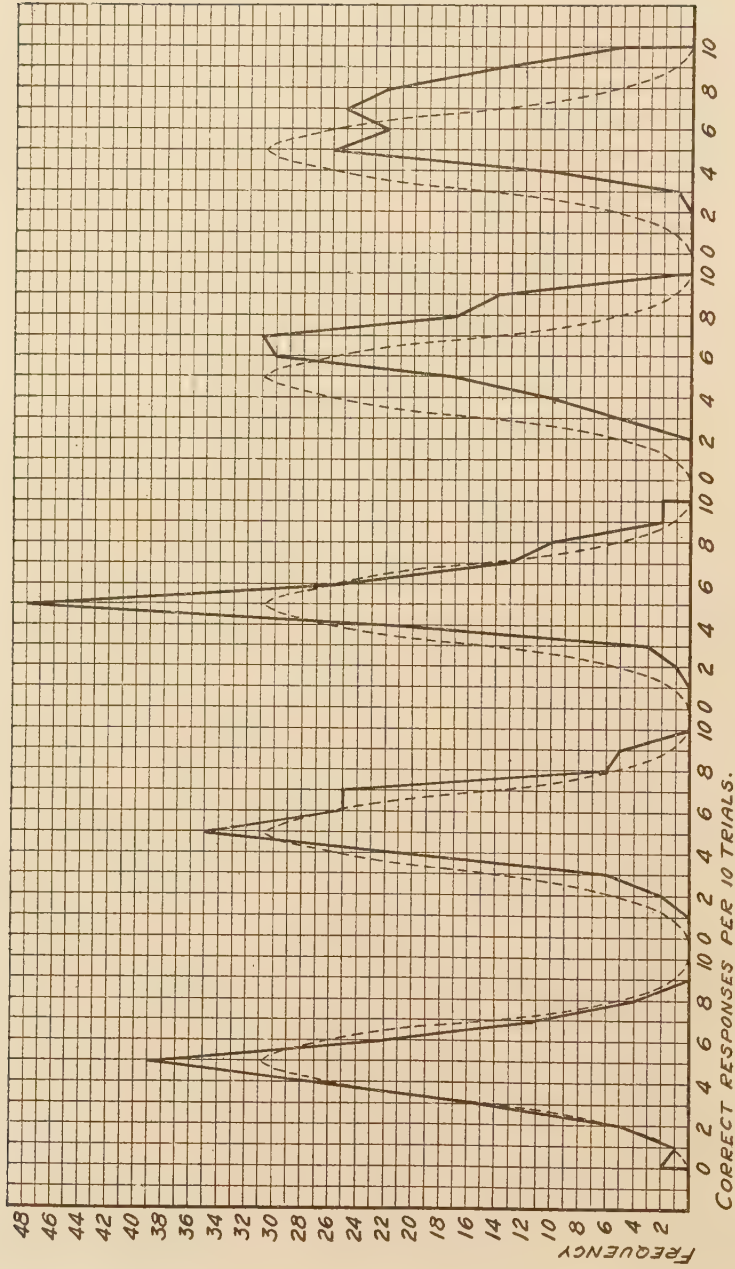


FIG. 4. FREQUENCY CURVE OF CORRECT RESPONSES FOR 5 ANIMALS

The curves represent intervals of 250 trials for the first 1350 trials exclusive of the intervals during which no tone was given. The dotted curves represent the theoretical chance distribution.

responses for the 5 rats in each series of 10 trials is plotted against the frequency of the scores. The curves represent intervals of 250 trials for the first 1350 trials, exclusive of the intervals during which no tone was given. The dotted curves represent the theoretical chance distribution. The gradual skewing of the experimental curves toward the end of increasing success is obvious. The humps developing on the right limbs of the curves represent the more rapid progress of nos. 2, 3 and 4 over that of 1 and 5, while the peaks at the 50 per cent mark in the first three curves indicate the dogged persistence of the position habit. An interesting side-light on this tendency is provided by a consideration of the relative number of errors made with and without sound. This data is given in the last two columns of table 1 beginning with the twenty-first series of 10 trials. Prior to that point the tone was given on both sides so that for the first twenty days the column headed "errors with sound" gives the errors with the sound on the left; and the column headed "errors without sound" gives the errors with the sound on the right. After the tone on the right-hand side had been abandoned and the animals were required to go to the right with the tone on the left and to the left with silence, they made about twice as many errors with sound as without. That is, they exhibited a tendency to go to the left rather than to the right. After the first 100 trials following the elimination of the right-hand tone, however, the condition was reversed and more errors were made with silence than with the tone, i.e., the rats now developed a tendency to go to the right which they maintained practically to the end of the experiment. That this was not the result of a simple position habit is shown by the absence of the unbroken succession of turns in one direction which characterizes this type of response. Indeed, the very fact that a record of about 75 per cent was maintained for a long period of time indicates that there was no true position habit. The data might better be explained by assuming that actually two habits were being formed rather than one, i.e., the animal was establishing an association between a definite and probably localized sound stimulus and a turn to the right, while at the same time another association was being formed between a turn to the left

and the ambiguous situation of no definite stimulus. The fact that toward the end of the experiment the animals were making fewer errors with the tone than with silence might indicate then that the former of the above two habits was the easier to establish.

EXPERIMENT III

With the stimulus situation as it was in the first experiment it was possible that the animals were forming the habit either around unlocalized tone or around tone as coming from a definite place away from which they must go. It was decided to test this by again introducing the tone on the right-hand side of the discrimination box. The rats were now required to go to the right with a tone on the left and to the left with a tone on the right instead of with silence. If this caused little or no disturbance it would indicate that the animals were localizing the tone and learning to go away from it, while a breakdown of the habit would indicate that they were rather setting up an association between tone, without reference to location, and a turn to the right. Furthermore, if the habit was maintained under the conditions of this experiment the possibility that the rats were receiving their cue from the vibrations of the floor would be effectually disposed of.

Results. The results of the third experiment are given in table 2 and figure 5. It will be observed that for the 30 trials following the change no. 2 gave no evidence of the slightest disturbance, while nos. 3, 4 and 5 fell slightly. Thereafter the record of no. 2 dropped off somewhat and they all became more variable in their responses than was the case in the previous experiment. This variability was probably in part due to the fact that the animals exhibited a greater amount of sexual activity at this time and since the 3 females and the male were caged together a more or less chronic condition of emotional disturbance was doubtless the result. This diagnosis is substantiated by the fact that all 3 females gave birth to litters a few weeks after the close of the experiment.

Despite the variability, however, some of the animals at least were unquestionably discriminating between the two sources of

sound. Rats 2, 3 and 4 gave records of 73, 74 and 64 per cent respectively for the 300 trials. The fact that the tone was going

TABLE 2

SERIES OF 10 TRIALS	DATE		CORRECT RESPONSES PER 10 TRIALS					MEAN FOR 10 TRIALS	MEAN FOR 50 TRIALS
			RAT 1	RAT 2	RAT 3	RAT 4	RAT 5		
1	10/21		5	8	5	7	7	6.4	
2			6	9	8	5	5	6.6	
3	22		5	8	7	7	6	6.6	
4			5	7	8	3	8	6.2	
5	23		7	7	5	6	2	5.4	
		MEAN	5.6	7.8	6.6	5.6	5.6		6.24
		σ	.80	.98	1.35	1.49	2.00	1.32	
6			6	10	6	8	7	7.4	
7	24		7	4	7	7	5	6.0	
8			7	7	6	6	5	6.2	
9	25		6	7	6	6	6	6.2	
10			5	5	7	6	8	6.2	
		MEAN	6.2	6.6	6.4	6.6	6.2		6.40
		σ	.98	2.00	.49	.80	1.16	1.09	
11	26		5	8	8	6	8	7.0	
12			5	7	7	6	7	6.4	
13	27		4	8	8	4	8	6.4	
14			6	9	9	7	6	7.4	
15	28		5	6	8	9	6	6.8	
		MEAN	5.0	7.6	8.0	6.4	7.0		6.80
		σ	.63	1.02	.63	1.62	1.26	1.03	
16			5	8	6	5	6	6.0	
17	29		5	7	8	8	4	6.4	
18			5	8	6	5	5	5.8	
19	30		6	8	7	6	8	7.0	
20			7	10	8	8	9	8.4	
		MEAN	5.6	8.2	7.0	6.4	6.4		6.72
		σ	.80	.97	1.26	1.35	1.85	1.24	
21	31		6	7	8	4	6	6.2	
22			5	7	5	5	3	5.0	
23	11/1		6	4	9	8	7	6.8	
24			6	5	9	6	8	6.8	
25	2		5	8	9	10	3	7.0	
		MEAN	5.6	6.2	8.0	6.6	5.4		6.36
		σ	.49	1.47	1.55	2.15	2.06	1.54	
26			5	8	9	8	3	6.6	
27	3		4	7	8	5	5	5.8	
28			5	6	9	7	7	6.8	
29	4		6	8	7	7	6	6.8	
30			7	8	9	8	7	7.8	
		MEAN	5.4	7.4	8.4	7.0	5.6		6.76
		σ	1.02	.80	.80	1.09	1.49	1.04	

continuously with practically constant pitch and intensity renders negligible the possibility that the animals were reacting to vibra-

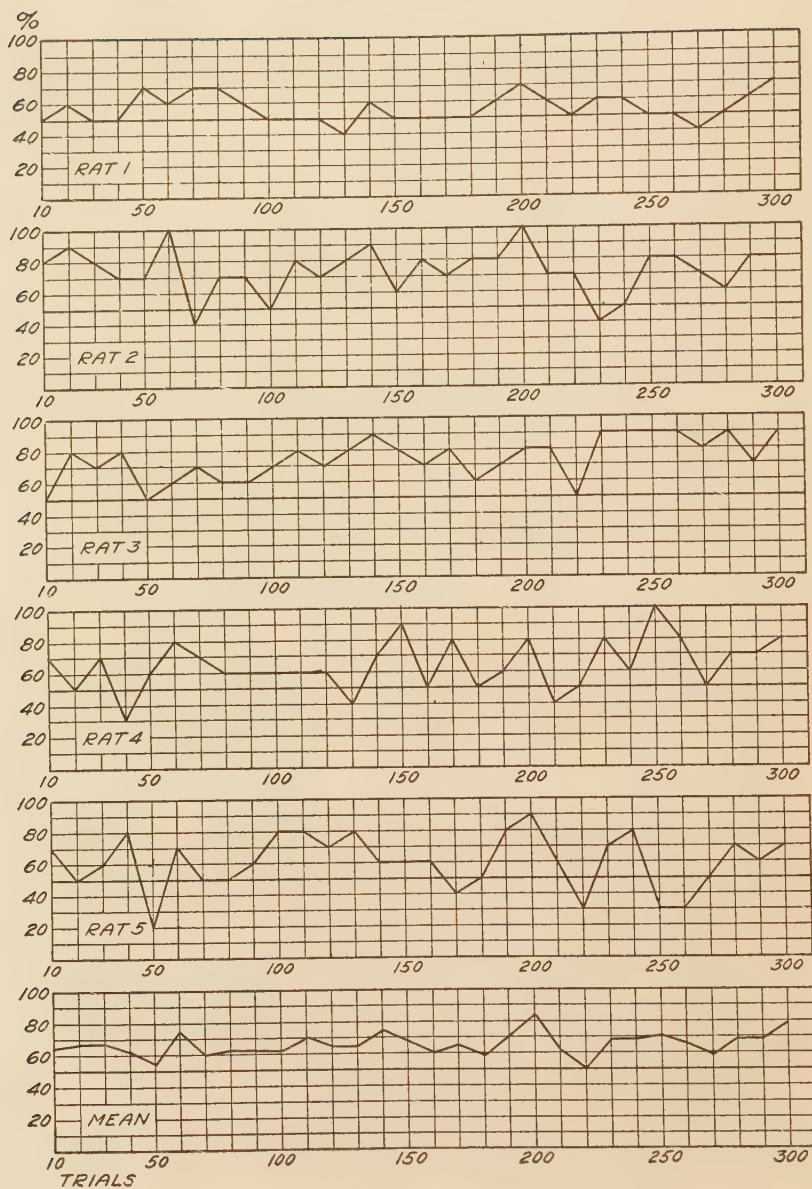


FIG. 5. LEARNING CURVES FOR EXPERIMENT III

These are the continuations of the curves of figure 3 and show the effect of introducing the second sound source.

tions of the floor. They were also running in the dark with the experimenter stationed outside the sound-proof room, so the conclusion seems justified that they were responding to the tonal stimulus. While nos. 1 and 5 hovered slightly above 50 per cent consistently, they never remained far enough above to make the evidence of learning unequivocal.

The failure of the change to cause any disturbance in the record of no. 2 indicates that she was doubtless responding to the tone in a definite location and had learned to turn away from it. The disturbance evidenced by the records of the other rats was not sufficiently marked to be easily interpretable. They may have been reacting as was no. 2, in which case the change in conditions probably operated as a slight confusion or emotional upset.

DISCUSSION

From the evidence presented in the foregoing pages it seems reasonable to conclude that some rats at least are capable of responding to tones to the extent of establishing the simple discrimination box habit. Hunter's experiments may therefore be interpreted as indicating that the rat responds much more readily to noise than to tone, rather than as showing that these animals are capable of reacting to tonal stimuli. A thoroughly satisfactory explanation of this condition, however, is by no means apparent. Plainly the association of a definite motor response with a tonal stimulus is not an easy one for the animal to set up and seems to belong in a different category from that of the discrimination of lights or noises. In situations of the latter type the animals quickly establish the habit and maintain nearly perfect records for considerable periods of time, but with tones the association is formed with difficulty and consistently perfect records are not attained at least within the limits of the present experiment.

While these results might be explained by assuming that the tone was one approaching the threshold of audibility for the rat, such a conclusion seems highly questionable in view of the fact that the animals were only slightly disturbed by a pronounced reduction in the stimulus intensity. The facts rather seem to indicate that the place characteristic of the tone is the key factor, or in

other words, that the rapidity with which the rat forms the association is largely a function of the degree to which he can localize the tone. This hypothesis might well explain the failure of the rats in the first experiment to learn the response after nearly 500 trials, for in this case the sound source was located directly behind the animal and presumably therefore more difficult to localize. However, further and more weighty evidence in favor of this conclusion is revealed by a comparison of the results of the second and third experiments. Thus it will be observed from a study of the curves in figures 3 and 5 that the degree of disturbance caused by the introduction of the right-hand tone was inversely proportional to the rapidity with which the habit of discriminating between tone and silence was formed. Thus no. 2 whose curve began to rise after about 300 trials showed not the slightest disturbance at the introduction of the second tone, while nos. 3 and 4 who required much longer to set up the first association were markedly disturbed at the beginning of the third experiment. Indeed after 300 trials no. 4 had not attained the degree of perfection which he exhibited in the previous experiment.

The failure of the animals to maintain a consistently high record may be at least partially accounted for by assuming an imperfect localization which would send the rat into error even though the habit of going away from the tone were perfectly learned. Then also if this habit were but partially formed errors of this sort would operate to confuse the animal and hinder the further progress of the learning.

It is the intention of the writer to test further the rôle played by localization in learning discrimination of noises and light in experiments similar to the present. Thus it would be of interest to know how rapidly under the conditions of this experiment rats react to easily localizable noises and to changes in general illumination. Heretofore, experiments in light discriminations have required the animals to react to relatively small areas of light in definite locations. It is proposed therefore to alter this situation in such a manner as to make it more comparable with the experiments on tone by requiring the rat to discriminate between widely different brightnesses of a diffuse illumination of the discrimina-

tion box. To be sure, if the rat uses vision to any great extent in running through the box a reduction in general illumination would hinder his progress through the alleys in a way in which a weak tonal stimulus would not. As a result we might expect the animal to react to changes in illumination more readily than to tonal stimuli. However, a comparison of the reaction to definite spots of light and to changes in diffuse illumination might reveal any effect in learning of the place character of the stimulus.

SUMMARY

1. In the first experiment 4 rats failed to learn to go to the right with a tone of 1024 d.v. and to the left with silence in 490 trials when the sound box was located directly in front of the entrance to the discrimination box.

2. With the alleys of the discrimination box lengthened, the sound source moved to one side, and with other changes described in the text, 4 out of 5 rats gave distinct evidence of learning to go to the right with a tone of 3072 dv. on the left and to the left with silence.

3. With a second sound source identical with the first introduced on the right-hand side of the discrimination box these animals gave distinct evidence of learning to go to the right with a tone on the left and to the left with a tone on the right.

4. The various controls introduced in the above procedure permit the conclusion that the white rat is capable of forming the discrimination box habit on the basis of tonal stimuli.

5. It is suggested that the ability to localize the tone may determine in part the rapidity with which the habit is formed.

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